Current Die Thinning and Bonding Technologies for Solar Sails -An Overview

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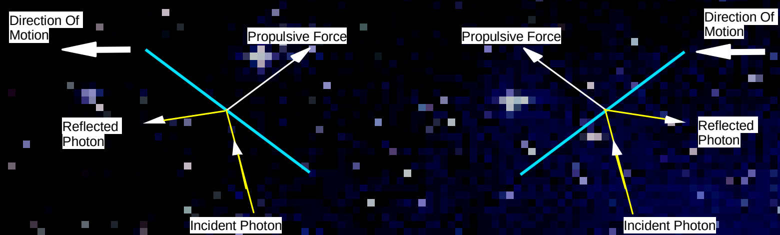
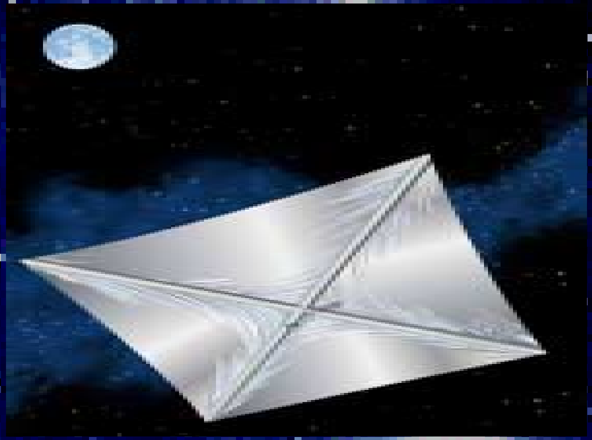
Introduction

Basics of Solar Sails

Basics



- *Solar sails are large ultra-light mirrors which use light from the sun (or a laser) for low-thrust propulsion.*
- *Photons bounce off the sail surface.*
- *Change in photon momentum transferred to sail.*
- *A mirror will be pushed twice: on impact and on reflection*
- *Sun/sail orientation controls orbital velocity*



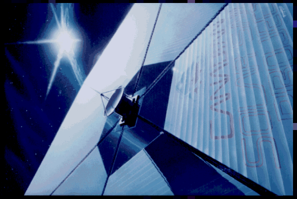
Advantages

No need to carry onboard propulsion system or fuel.

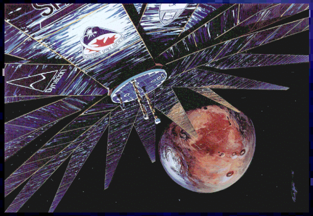
- *Reduced mass allows greater payload capacity and much shorter trip times for high energy missions.*
- *Constant low thrust counteracts gravity to enable unique non-Keplerian orbits and new vantage points.*
- *Sails that use laser energy beamed from Earth may enable rapid access to the interstellar environment.*

Types

Square



Circular

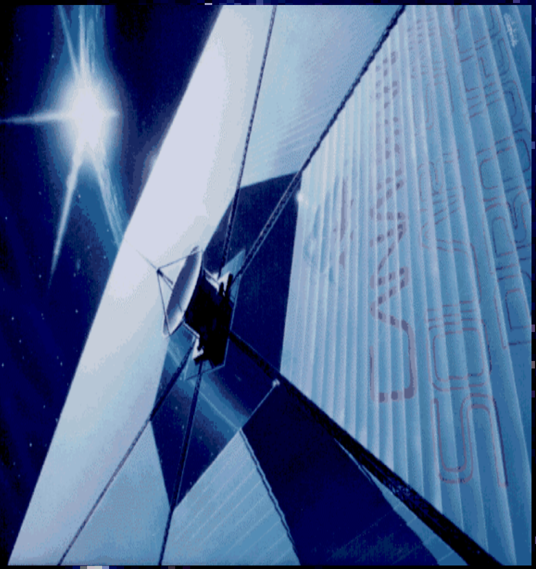


Heliogyro

Blade Sail

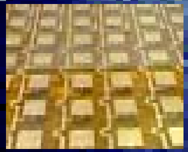
Introduction
Future Solar Sails

- *Highly-integrated solar sails consist of thin membrane partly populated with multifunctional patches.*



Sensors

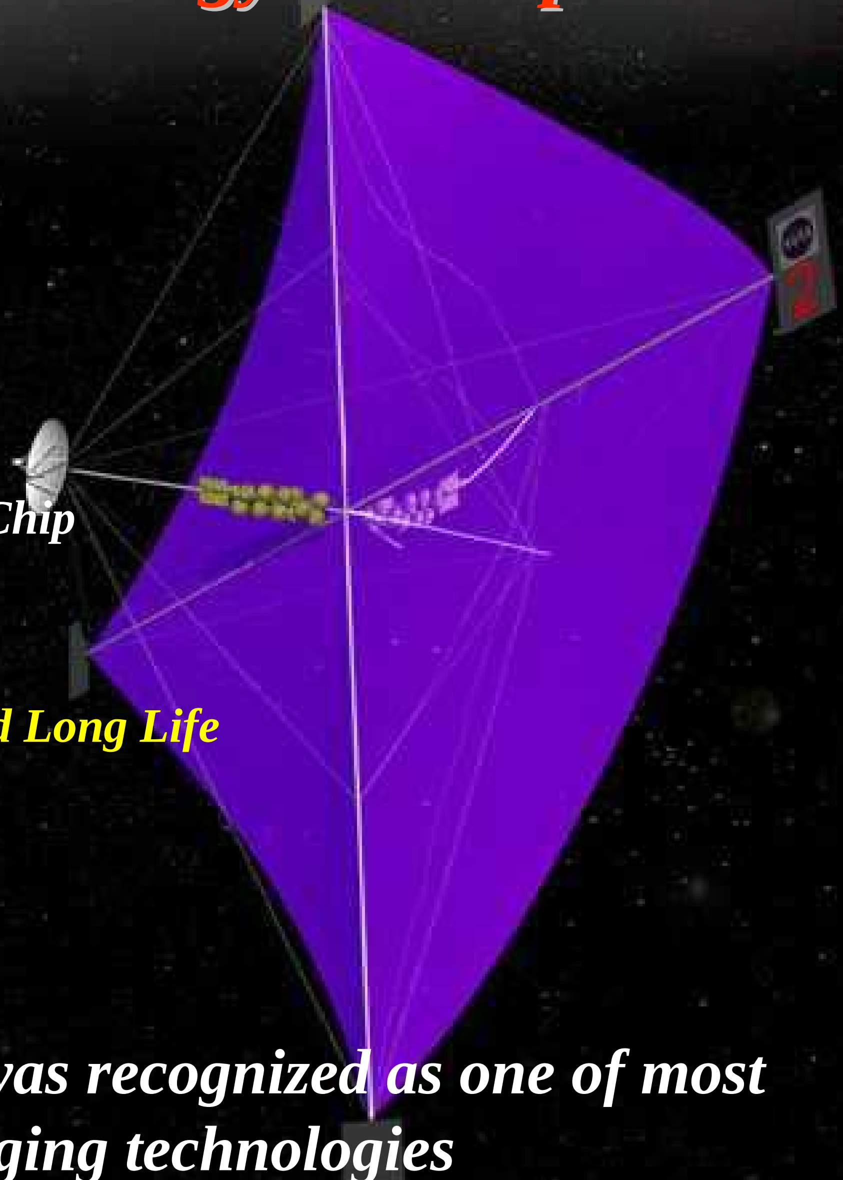
Thin Film Photovoltaics



Phased Array Elements

Flexible Electronics

Solar Sails
Areas of Technology Development



- *Architecture and Planning*
- *Sail Development*
- *Advanced Packaging*
  - *Thinned Die on Film*
  - *Instruments & Sensors-on-a-Chip*
  - *Wireless / Distributed Systems*
- *Large Structure Environments and Long Life*
- *Large Lightweight Structures*

Thinned dies on film was recognized as one of most important and challenging technologies

Overview Objectives

- Perform a review of the current technologies for thinning of silicon die and bonding onto membranes.

- Find out if existing technologies are applicable to solar sails

- Outline study's conclusions and recommendations for possible follow-on activities.

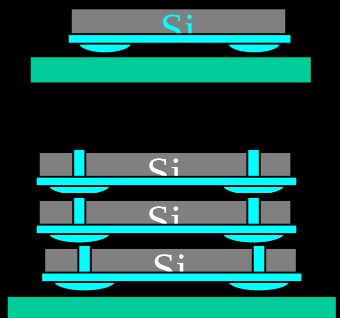
Die Thinning/Bonding Requirements

- *Silicon based die*
- *Ultra-light weight*
- *Thickness: as thin as possible (microns)*
- *Flexible/high bending capability*
- *Attachable to polymeric membrane*
- *Long term high reliability (> 10 years)*
    - *Mech./thermal/electrical functionalities*
    - *High/low temps resistant*
    - *Thermo-mech. cycling resistant*
    - *Space radiation resistant*

Die Thinning General Trend

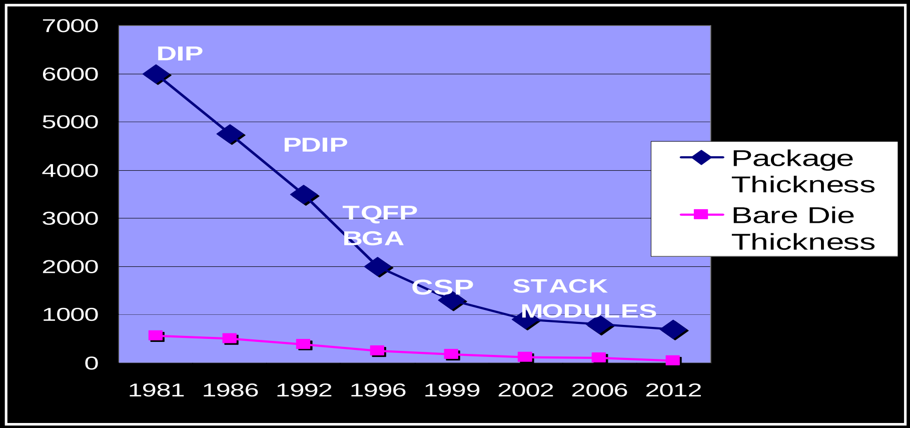
- *Historically wafer thinning has been used:*
  - *Achieve a uniform thickness*
  - *When heat was a problem*
  - *For most applications wafers were not thinned*

- *Today, that is changing*
  - *New miniature packages and applications*
  - *Needs for higher I/O, increased performance & speed*
  - *Demands for high packaging density*



Number of components in 3D space would double every 18 – 24 months

- *Solution: vertical miniaturization*
  - *Die thinning (t < 250 μ)*
  - *Thinned 3D stacking (thickness ~ 0.4 mm)*



* Tru-Si Technologies

IC packaging "smaller is better – thinner is better"

Die Thinning Advantages/Applications

Advantages/Benefits

- Smaller package profile
- More flexible
- Increased performance
- Better reliability
- Smaller saw street dimensions

* 50 μm wafer (Tru-Si Technologies)

•Applications

- Space, military, commercial and medical
- Numerous handheld, portable and miniature applications
- Memory cards, smart cards, small disk drives, cell phones, portable computing and other consumer electronics

Die Thinning
Current Techniques

- ***How to thin a silicon die/wafer***

  - ***Mechanical grinding/polishing***

  - ***Wet etching***

  - ***Dry plasma etch***

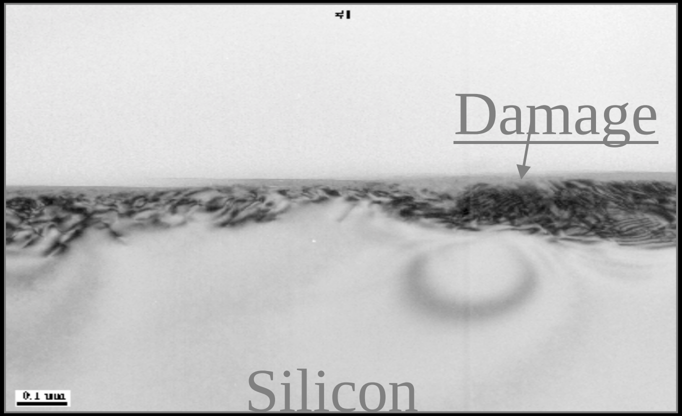
Die Thinning
Grinding

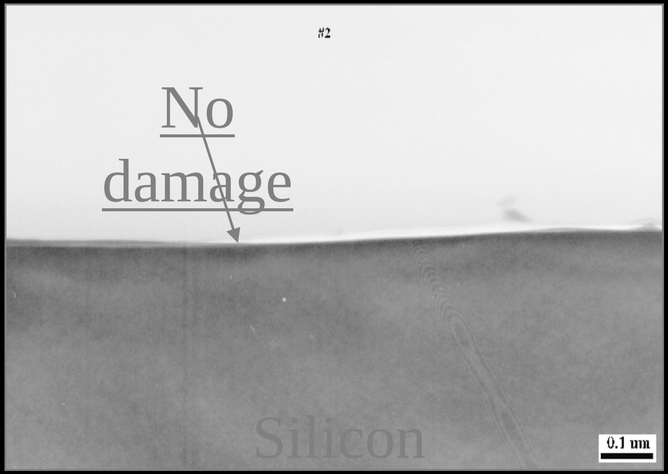
- Efficient method at very modest cost and high throughput for thickness > 250 μ
- First step of thinning

- Grinding drawbacks
  - Introduces micro-cracks, residual stress and surface roughness
  - Causes structural damage and lattice disclocations
  - Creates a warpage and bow
  - Reduces mechanical and electrical properties
  - Need a front side protection

- Damage shall be removed by other thinning methods

- Numerous improvements





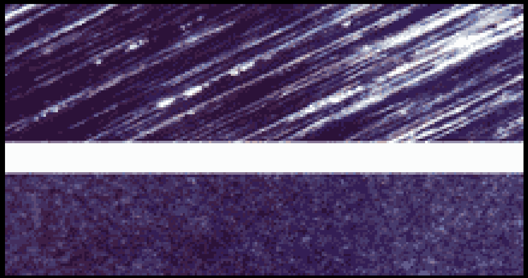
* Tru-Si Technologies

Die Thinning
Wet Etch

- Follows the grinding step
- Can be used to remove the damage layers

- Benefits
  - substantially reduces the stress level
  - reduces the warpage
  - removes micro-cracks and lattice disclocations
  - results in a much stronger wafer/die

- Drawbacks
  - requires a protection of front surface
  - not practical with bumped wafers/dies
  - no good wafer/die thinning uniformity
  - increasing difficulty when a thickness < 250 μ



Before and after etching

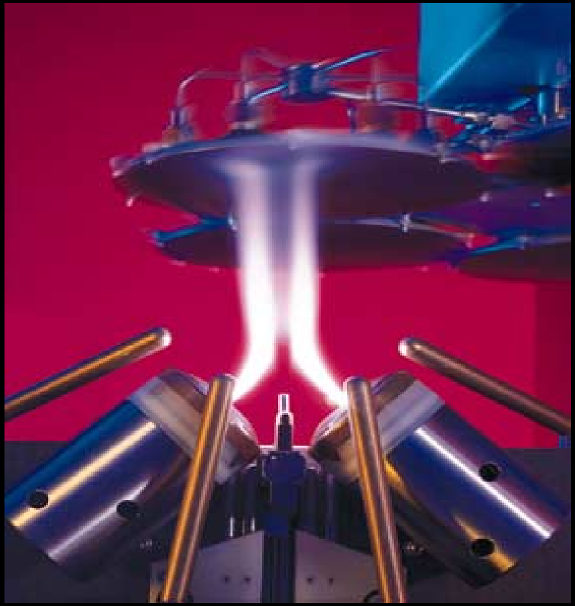
Die Thinning
Dry Plasma Etch

Conventional anisotropic low pressure systems :

- *operate in vacuum*
- *require sophisticated vacuum systems*
- *slow process and low etch rates*

New Atmospheric Downstream Plasma (ADP) developed by Tru-Si Technologies:

- *operate at ambient pressure*
- *isotropic plasma-etch system*
- *higher etch rates*
- *design/controls eliminate potential overheating, contamination, etching, thickness non-uniformity, ESD etc*



ADP system

Die Thinning
ADP by Tru-Si Technologies

•*Process description*

- Magnetically controlled, inert gas DC arc plasma discharge

- ADP brings reactant gas (FC_4) to the plasma region

- Gas is decomposed and available for reaction

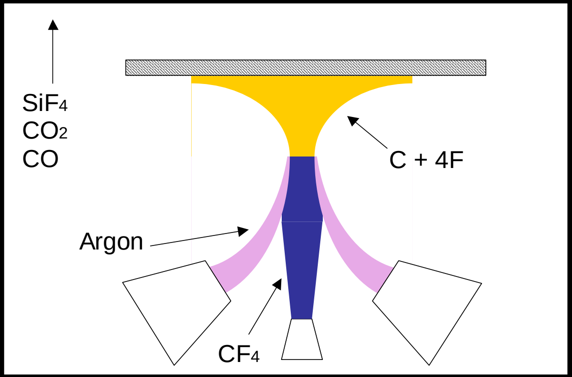
- F reacts with Si and produces the etching

- C byproduct react with O_2 and is prevented from being deposited

- Charged particles recombine outside the plasma

- Lower power density

- Short & repeated exposures to the reaction zone



Die Thinning
Atmospheric Downstream Plasma

Benefits

- *operate at ambient pressure*

- etch rates at least 20 x > vacuum plasma

- no surface/structural damage nor residual stress

- no front side protection

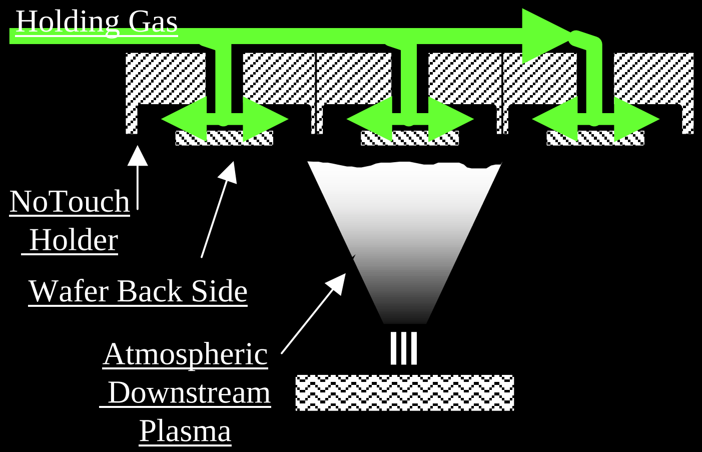
- isotropic and uniform etching

- control of plasma power density and location

- no overheating nor plasma contamination

- no electrical damage

- perfect for thinning of wafers/die with bumps



No Touch ™ holding

- surface temp. < 125^{0}C

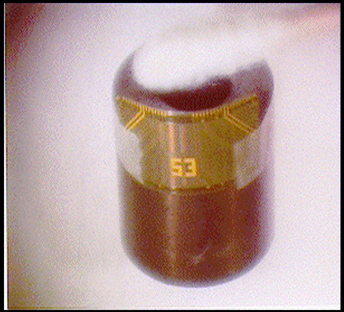
- ideal for damage/stress removal and final thinning

Die Thinning
At Irvine Sensors Corp.

- ***Proprietary multiple-step grinding/polishing***

- 4 and 16 Mb flash wafers were thinned to 25-35 μ
- Chip size was 419 x 449 mils

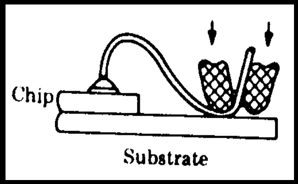
- 1 Mb SRAM wafer sections were thinned to 30-35 μ
- Chip size was 277 x 542 mils



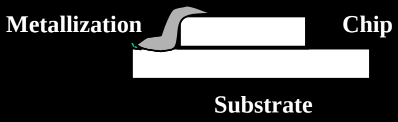
- Kapton based flexible test vehicle has been used to test ultra-thin flash die.
- Thinned chips were smooth, flexible and electrically functional
- Residual stress too small to measure

Die Bonding
Current Methods

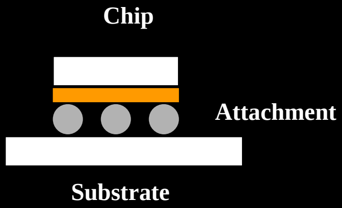
- *How to attach a thinned die to flexible membrane*



- Wire bonding



- Direct attach



- Flip chip

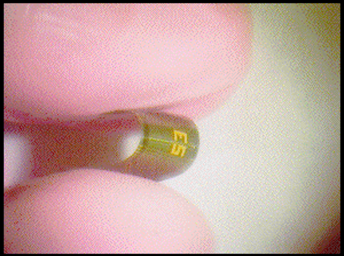
- Only a few organizations involved

Die Bonding
At Irvine Sensors Corp.

- *Three bonding methods had been investigated*

- *Wire & direct bonding failed*

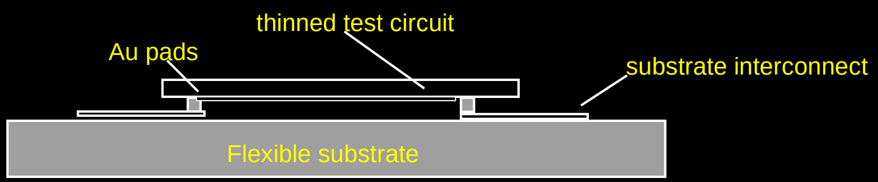
- *Flip chip bonding was successful:*
  - *25 μ thin Flash die face-down*
  - *Z-conductive epoxy*
  - *25 μ Cu laminated Kapton substrate*
  - *2-3 μ Au pad*



Testing indicated good electrical and mechanical performance after repeated bending & thermal cycling

Die Bonding
At Irvine Sensors Corp.

- ***Reliability testing***



Test sample

Temperature cycling (+80 ^{0}C to –60 ^{0}C)

- No failure or change in resistance

- No structural degradation

Bending testing;

- 10 mm curvature

- 4 lbs uniaxial load

- 10,000 cycles

Post-testing evaluation:

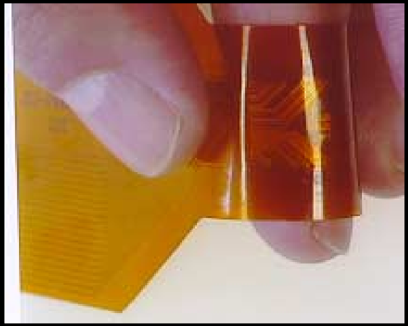
- Good structural integrity

- No change in reverse and DC leaking

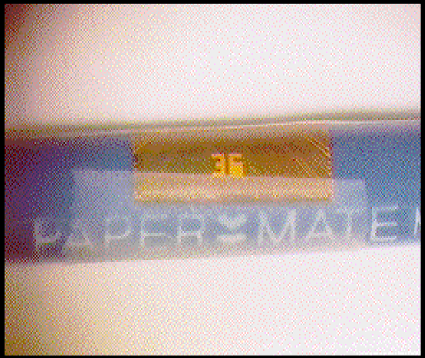
Bending of Flash die

Die Bonding
At University of Arkansas

- *Integration of thin (20-35 μ) Si chip-on-flex membrane Demonstration in flip chip and face-up configuration*



- *Integration of chip carrying polymer patch-on-flex membrane*



- *Chip-on-membrane and chip carrying patch-on-membrane samples were successfully tested*

Conclusions/Recommendations

- *Preliminary studies indicate the feasibility of thinning of Si die to few tens microns and bonding it to flexible membrane.*

- *It appears thin chip-on-membrane systems can be made sufficiently reliable to satisfy solar sails requirements.*

- *There are several possible techniques to choose from.*

- *Further evaluation and verification of selected thinning/bonding technologies are recommended for specific flexible sensors and electronics for solar sails.*